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CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE. E. L. MARK, DIRECTOR.—No. 154.

A SIMPLE APPARATUS FOR AËRATING LIQUID SOLUTIONS.

S. O. MAST.

IN studying the effect of dilute and concentrated solutions of sea water on marine algæ it became necessary to aërate the solutions in order to keep them fresh. For this purpose a very simple piece of apparatus was devised. The apparatus was used slowly to concentrate or dilute the solutions as well as to aërate them. It has now been in continuous operation for over three months and has proved to be so effective, to require so little care, and to be so easily made, that a brief description of it may be useful to others.

The general structure of the apparatus will be readily understood by referring to the accompanying figures. It will only be necessary then to discuss a few details of its structure and the principles on which its operation depends.

The aërating tubes used in the experiments mentioned above are 90 cm. long and 4.5 mm. in diameter (inside measure), which is constricted to 0.5 mm. at a point 7 cm. from the upper end. The capillary siphon is 0.75 mm. in diameter; the solution in the culture jar is 27 cm. deep. It will readily be seen that, since the aërating tube is much larger than the capillary siphon, if both are to be constantly full the solution must flow much more slowly in the tube than in the siphon.

Owing to the action of gravitation, however, the motion of the solution tends to accelerate as it falls, and therefore tends to flow faster in the aërating tube than in the siphon; so that the solution in the tube as it flows through the constriction is broken into very short columns separated by small bubbles of air, which incidentally aërates the solution. Several of these columns unite, forming larger ones as they flow down the tube, as do the bubbles also. The relative lengths of these columns of solution and spaces of air depend upon three factors: (1) The difference between the diameter of the capil-

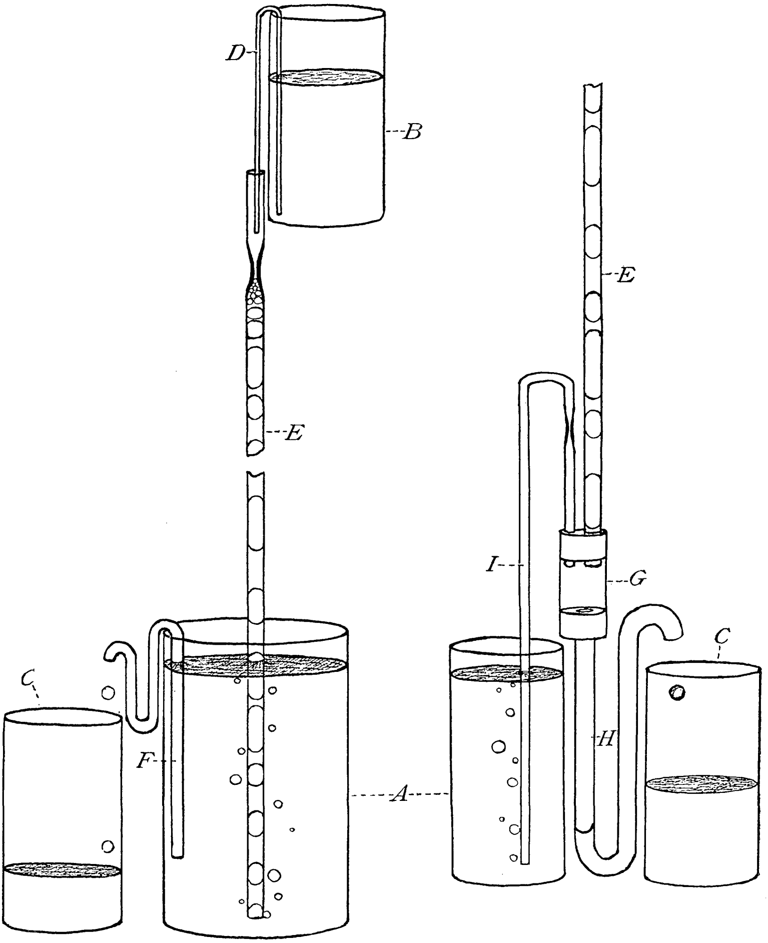

FIG. 1. FIG. 2.

FIG. 1. — An aërating apparatus in which the liquid used to aërate flows into the culture jar. FIG. 2. — A similar apparatus in which the liquid does not flow into the culture jar. *A*, a culture jar, *i. e.*, a jar containing a solution to be aërated; *B*, a supply jar; *C*, an overflow jar; *D*, a capillary siphon; *E*, an aërating tube; *F*, a constant-level siphon; *G*, *H* and *I*, accessories to the aërating tube.

lary siphon and that of the aërating tube, (2) the length of the aërating tube, and (3) the depth of the solution in the culture jar. All that is necessary in order to increase the amount of air, as compared with that of the solution in the tube, is to increase either the diameter or length of the aërating tube or to decrease the depth of the solution in the culture jar.

If the diameter of the tube is increased and the flow kept constant it is clear that more air must be taken in to fill the increased space due to the enlargement. But as the diameter increases the adhesive force between the walls of the tube and the solution in it decreases, as compared with the cohesive force of the solution, so that when a certain diameter is reached the bubbles of air break through the columns of solution and thus can no longer be forced to the bottom of the tube in the culture jar. As a matter of fact, the maximum limit of diameter in the case of water is practically about 4.5 mm. Further, if the rate of flow in the aërating tube be in any way increased while that in the siphon remains constant, more air will be required to keep the tube full, just as in case of an increase in diameter. The rate of flow in the tube, however, varies directly with the length of the tube; and since there is no theoretical limit to the possible length of the tube, the amount of air compared with that of solution can be theoretically increased indefinitely. The depth of the culture solution is really a function of the length of the aërating tube. In order to overcome the pressure of the culture liquid and force the air out at the bottom of the aërating tube, it is necessary to have a column of solution in the tube *above* the level of the solution in the culture jar slightly greater than the air space in the tube *below* that level. Consequently the portion of the tube which is below the level of the solution in the culture jar and enough of it above that level to contain as much solution as there is air below, have nothing to do with increase in acceleration due to gravitation, for they simply balance each other, and therefore these parts are not effective in increasing the amount of air introduced. This being true, it will readily be seen that increasing the depth of the culture solution has the same effect as decreasing the length of the aërating tube, and that therefore the deeper this solution, other things being equal, the less will be the air forced through.

The purpose of the constriction in the aërating tube is merely to break up the column of solution in the tube. If this were not thus broken up it would accumulate until it became slightly greater than the air spaces in the tube below the level of the culture fluid and then would suddenly flow down, forcing the air out with a rush, after which it would again accumulate, flow down, etc. This is just what happens if the constriction is not small enough in comparison with the size of the capillary siphon. A few experimental trials, however, will be sufficient to enable one to decide on the proper relative sizes of the two. No definite instruction can be given with reference to this since the diameter of the siphon must vary with the diameter and length of the aërating tube and with the depth, specific gravity and viscosity of the culture solution. In general the constriction should be somewhat smaller than the siphon.

In some forms of apparatus[1] the lower end of the aërating tube is bent on itself so as to project upwards in the culture solution and a small piece of sponge is then pressed rather tightly into this bent free end, or the tube may be drawn out into a capillary ending. It is claimed that the sponge, especially, breaks up the air into very small bubbles. This is undoubtedly true, but it has been found that in the apparatus represented in Figures 1 and 2 the pressure required to force the air through the sponge is so great that the value of this adjunct is questionable.

The most efficient and simplest method discovered to break up the air bubbles is as follows: Cut off the lower end of the aërating tube square, grind it quite flat, and let it rest on a firm piece of rubber, leather, or wood on the surface of which a considerable number of radiating grooves has been made. The piece of rubber rests on the bottom of the culture jar and the tube is placed over the point whence the grooves radiate. The grooves in any event must be narrow. Their depth should depend upon the weight of the aërating tube. If the tube is heavy it will sink into the surface upon which it rests, and therefore under such conditions the grooves must be deeper than if the tube is light. Although by this device the bubbles are not broken up as much as they can be by using a piece of sponge forced into the end of the tube, this method has the decided advantage of requiring much less pressure, and there is also much less danger of clogging the tube than if a sponge is used.

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[1] See H. Lenz. Verbesserung an den Durchlüftungsapparaten der Seewasser-Aquarien. *Zool. Anzeiger*, 1879, Jahrg. 2, pp. 20, 21.

In making the aërating constriction the tube should be heated, without being drawn out, until the walls fall in, as this causes them to become much thicker and consequently stronger than they otherwise would be.

It is much better to use a capillary siphon than a larger tube drawn out to a capillary ending; first, because a capillary siphon never needs to be filled, for when the supply jar is filled to within about 1 *cm.* of the top capillary attraction will fill the siphon and start it running; secondly, because a large tube drawn out at one end is much more readily clogged than a small one of equal diameter throughout.

The constant-level siphon (*F*) should be unquestionably large enough to drain off the solution as fast as it comes into the culture jar, but not much larger; neither should its outer end be more than a few centimeters lower than its highest point, for if it is the decrease in pressure at the highest point causes sufficient increase in vapor pressure of dissolved gases to cause them to be thrown out of solution, to collect at this point, and thus to clog the siphon.

The principles of operation in the second apparatus, that, represented in Figure 2, are in all respects similar to those discussed with reference to the apparatus represented in Figure 1. The upper end of the aërating tube, the capillary siphon, and the supply jar are the same as represented in Figure 1.

The chamber *G*, which serves to separate the air from the liquid, can be readily made by cutting off a test tube. It should be about 1.5 cm. in diameter and 4 or 5 cm. long. It must of course be air-tight. Ordinary corks soaked in paraffin will serve very well to close the ends.

The tube *H* should be at least 5 mm. in diameter, slightly larger than the aërating tube proper, *i. e.*, large enough to prevent air being forced through it with the solution. Its length must be such that its outer end is somewhat farther above its lower bend than the outer end of the tube *I* is below the surface of the solution in the culture jar; for if it is not the air will pass out through it instead of through the culture solution.

The tube *I* serves to convey the air from the chamber *G* into the culture solution. It may be of any size, length or form. The lumen through the constriction in it is very small; though not absolutely necessary, it serves to cause a more steady flow of air. A rubber tube with an adjustable pinch-cock might serve this purpose still better.

All that is necessary to operate either apparatus described, is to pour the solution from the overflow jar into the supply jar from time to time. The frequency required in this operation depends of course upon the size of the jars and the diameter of the capillary siphon. If, as in the experiment mentioned above, 4-liter jars and a 0.75 mm. siphon are used, a transfer once in three days will be quite sufficient.

In closing I wish to thank Dr. E. L. Mark for furnishing material which made the experiments referred to above possible, and for valuable criticism of the manuscript of this article.